Int. J. on Recent Trends in Engineering and Technology, Vol. 8, No. 1, Jan 2013

# Automata Modeling of Hormonal Molecular Communication Channel in Human Body

Partha P. Ray
Department of Computer Science and Applications, Sikkim University,
6th Mile, Gangtok, Sikkim-737102
Email: parthapratimray@hotmail.com

***Abstract*—Molecular communication nanonetwork has become an inevitable topic of research interest. Human body is a juxtapose of numerous nanonetworks. Hormonal communication channel in human body plays a vital role in homeostasis. This paper proposed a novel automata modeling of hormonal molecular communication channel in human body followed by a nano machine design. The outcomes of this literature will surely pave the path of advanced ICT based medical diagnostic approaches towards human health procurement.**

***Index Terms*—Nanonetwork, communication channel, hormone, finite state automata, moore machine, nano machine**

## I. Introduction

Nanonetwork is very recent area of emerging interdisciplinary research which includes biology, physics, chemistry, mathematics, electronics and computer science. As per the definition of nanonetwork, it is a set of interconnected nanomachines, i.e., devices in the order of a few hundred nanometers or a few micrometers at most, which are able to perform only very simple tasks such as computing, data storing, sensing and actuation [1]. It is enhancing the applications of nanotechnology in the various areas of development such as: medicine, industrial, military etc.

Molecular communication is the prime pillar of nanonetworking. It can be defined as the communication between molecules with different size, shape and activities either in electrochemical or behavioral. Human body is a nature made fantastic model of realistic nanonetworking. Hormonal communication is one of the important life saving techniques which always takes place inside body to maintain the homeostasis i.e., regulation of internal environment and maintaining a stable, constant condition.

As in macro level communication channels, hormonal communication channel is divided into three basic parts such as: transmitter, channel and receiver. Upon getting signal in cell receptors, glands secrete hormones into the blood vessels. The secreted hormones then aim at specific tissues and command them to produce specific substances.

Finite state automata helps in modeling certain systems to process a designated task in predefined state transitions, Moore machine is the variant of this automaton which produces output solely based upon its present state.

Though automata modeling of intra body molecular communication nanonetwork is an crucial footstep towards ICT based advanced medical diagnosis, a very limited amount of work has been done in this field so far. This paper proposes a novel Moore machine based upon hormonal communication channel in human body, which incorporates the proposed novel Hormonal Communication Algorithm-HCA. Later, a nano machine is also devised according to the developed Moore machine logic. The proposed model will surely pave the path for advanced medical diagnostic approaches to help human to live in better healthy condition.

This paper is organized as follows. Section II presents related work. Section III presents the basis of hormonal communication in human body. Section IV devises the Moore machine. Section V represents the nano machine.

## II. Related Work

Literature [2], [3] proposed Moore machine model which is adapted by comprehending biological interactions between nano scale neuro-spike communication and human auditory systems followed by a novel nano computer model which is devised based on Moore machine, respectively. [4] discussed various elementary models for intra-body molecular communication channels, such as, nanoscale neuro-spike communication channel, action potential based cardiomyocyte molecular communication channel, and hormonal molecular communication channel and their multi-terminal extensions. In [5], an analytical framework that incorporated the effect of mobility into the performance of electrochemical communication among nanomachines is presented. In [6], a physical channel for molecular communication is modeled by a linear time invariant (LTI) system, and the channel transfer function is derived. [7] proposed a stochastic dynamical model of noisy neural networks with complex architectures and discusses activation of neural networks by a stimulus, pacemakers and spontaneous activity. Paper [8] and [9] presented a molecular communication channel as a binary symmetric channel is modeled and its mutual information and capacity is analyzed. [10] proposed an information theoretical model to understand the signaling mechanism of the molecular communication medium. Thesis [11], represented the modeling of Finite State Automata (FSA) of quorum sensing mechanism in Bacteria and designs a nanomachine to implement Quorum Sensing. [12] presented a nanoscale neuro spike communication characteristics through development of a realistic physical channel model between two terminals. [13] seeked for synaptic Gaussian interference channel along with the characterization of power or firing rate of achievable rate


DOI: 01.IJRTET.8.1.35

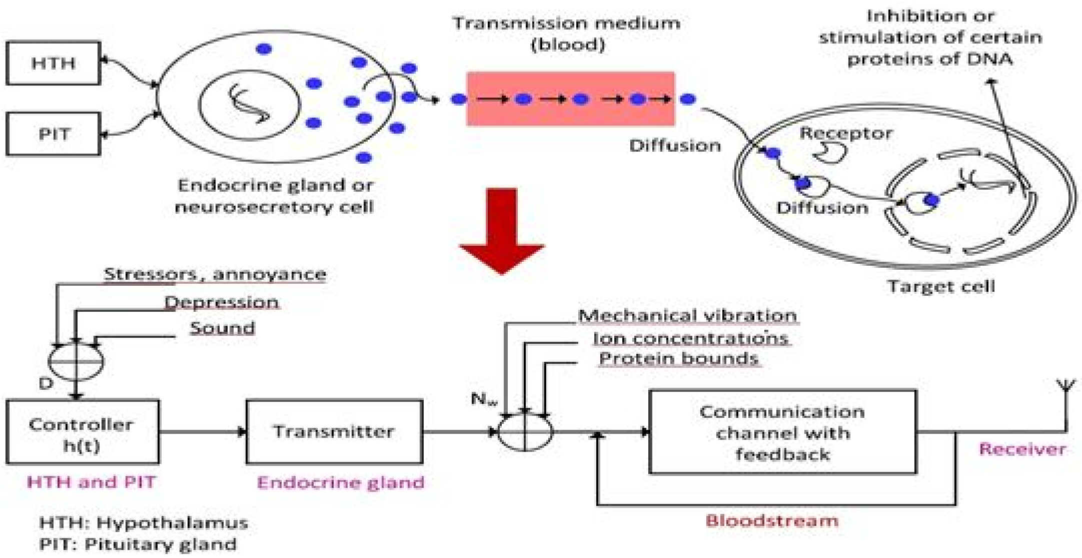


Figure 1. Hormonal molecular communication channel.

region for the channel.

## III. Basis of Hormonal Communication

Hormone [14] is a chemical released by a cell or a gland in one part of the body that sends out messages that affect cells in other parts of the organism. Hormones can be divided in two types based on their biochemistry. One is Lipid-soluble hormone such as, steroid which can easily penetrate the membrane of target cells. Other is Lipid-insoluble hormone which cannot penetrate the membrane of target cells but requires additional messengers to convey the message to cytoplasm of the target cells.

Endocrine glands are influenced by nervous impulses. Upon getting signal form nervous system, Hypothalamus gets awake to understand the meaning of signal and in turn Pituitary gland instructs endocrine glands to secret the appropriate biochemical into blood vessels as they are ductless (Fig. 1) [4]. The secreted messengers are broadcast to whole body but certain target tissues or cells understand the encoded meaning and decodes it and does specific tasks. Hence, endocrine systems act as sensor/actuator system.

The Fig. 1 describes all about hormonal communication channel where endocrine glands act as transmitter and target cells does the act of receiver. Bloodstream performs the job of communication channel. The channel is a negative feedback channel which is controlled by the concentration level of the target cells. Furthermore, the signal generation from HTH or PIT is controlled by disturbances D, such as, external stressors, annoyance, depression, or sound. Whereas transmitter side is susceptible to noise $N_w$ such as, mechanical vibration, ion concentration of target cells and protein bounds to the DNA of cells. There are few parameters which play important role in successful hormone delivery such as, concentration of the secreted biochemical, the concentration rate of their circulation in blood, metabolic clearance [15]. The circulation of hormones in side human body occurs due to the combination of diffusion process of blood and hormonal drift of diffusion.

## IV. Automata Modeling

Before moving towards making of Moore machine, the basic concept of Finite State Automata (FSA) and related contexts should be scripted.

### A. Finite State Automata (FSA)

An FSA is a mathematical model to conceive abstract machine which is a state at one time known as present state. When an event triggers up transition between states happened. Deterministic finite state automaton is a five -tuple as shown below. If A is a dfsa then it represents the below mentioned set. Deterministic FSA is described as below.

- *A deterministic finite state automaton is a system $A = \{Q, \Sigma, \delta, q_0, F\}$, where Q is a finite set of the possible internal states of the automaton A, $\Sigma$ is a finite alphabet, $q_0$ is the initial state, $\delta$ is the transition function ($\delta$: $Q\times\Sigma\rightarrow Q$) and F is a subset of Q, the set of final or acceptance states.*

### B. Moore machine

Moore machine is a variant of deterministic finite state automaton in which each state is bound to an output which depends upon present state only. It is a six-tuple set which resembles the dfsa but differs in output function and output alphabet. The model for the hormonal molecular communication channel is based on a Moore machine, since all the transitions are fixed, and an output is to be defined.

- *A Moore machine is a six-tuple $A = \{Q, \Sigma\, \Lambda, \delta, \tau, q_0\}$, where Q is a finite set of the possible internal states of the automaton A, $\Sigma$ and $\Lambda$ are finite alphabets for the input and the output, respectively, $q_0$ is the initial state, $\delta$ is the transition function ($\delta$: $Q\times\Sigma\rightarrow Q$) and $\tau$ is the output function ($\tau : Q\rightarrow\Lambda$).*

### C. Hormonal Communication Algorithm

The proposed Moore machine of this paper takes the channel model of novel hormonal communication in human body as basis of design. The machine works on the logic




DOI: 01.IJRTET.8.1.35

behind the HCA i.e. Hormonal Communication Algorithm.

HCA: Hormonal Communication Algorithm

```
Begin
Inputs:
 H(t)= HTH(t) * P(t)
 D(t)= St(t)*A(t) * Dp(t) * S(t)
 Nw(t)= V(t) * Ic(t) * Pb(t)
 Hr(t)= Hcp(t) * Hdp(t)
 Hd(t)=Hsc(t) * Hcc(t) * Hr(t)
 Hrc(t)= Htd(t) * Hip(t)
1. Transmission of Hormone:
        If (D(t) > = Dth)
      If (H(t)>= Hth and Nw(t)>=Nth)
      Then
                  Secret Hormone;
           End If
       Else
      Goto step 1;
     End If
2. Circulation of Hormone:
        If (Hp(t) >= Bc(t) + Hfd(t))
      Then
              If (Hd(t)>=Hdth)
                Then
   Hormone circulation      success;
               End if
     Else
          Circulation failure;
          Goto step 2;
     End If
3. Receive of Hormone in target cells:
        If (Hrc(t))
      Then
                Produce specific stimulus;
                Generate negative feedback;
                Goto step 1;
     Else
          Goto step 3;
     End If
End
```

Figure 2. Hormonal Communication Algorithm-HCA

The above proposed algorithm lays a foundation of automata modeling of hormonal communication channel in human body. The HCA uses few abbreviation such as, H(t)-nervous network control over hormone regulation, HTH(t)-hypothalamus signal, P(t)-pituitary command signal, D(t)-disurbance factor, $S_t(t)$-stress, A(t)-annoyance, $D_p(t)$-depression, S(t)-sound, $N_w(t)$-Noise, V(t)-mechanical vibration, $I_c(t)$-ion concentration, $P_b(t)$-protein bound, $H_r(t)$-hormonal removal rate, $H_{cp}(t)$- hormonal concentration in plasma, $H_{dp}(t)$-hormonal disappearance rate from plasma, $H_d(t)$-hormonal successful delivery rate, $H_{sc}(t)$-hormonal secretion rate, $H_{cc}(t)$-hormonal circulation rate, $H_{rc}(t)$-hormone reception rate, $H_{td}(t)$-time delay between hormone transmission and reception at target cells, $H_{ip}(t)$-input hormonal behavior, $D_{th}$-disturbance threshold value, $H_{th}$-hormonal regulatory threshold controlled by nervous network, $N_{th}$-noise threshold, $H_p(t)$-hormonal propagation rate, $B_c(t)$-blood circulation rate, $H_{fd}(t)$-hormonal free diffusion rate, $H_{dth}$-hormone delivery threshold rate.

The above mentioned parameters act as inputs to the HCA. Algorithm is partitioned into mainly three parts such as: transmission, circulation and reception of hormone. After satisfying simple if-else block in part 1 in HCA system moves towards circulation stage. In circulation phase system encounters another if-else block and based upon the outcome system moves to third and last phase of the HCA. The HCA is a linear algorithm whose run time can be calculated as: $\mathbf{O}\left(H_p(t) + H_d(t) + H_{rc}(t)\right) \cong \mathbf{O}\left(H_d(t) + H_{rc}(t)\right)$; as $H_d(t) >> H_p(t)$.

### *D. Moore machine construction*

Fig. 3 presents the proposed Moore machine based on the HCA shown in Fig. 2. The machine consists of six states, such as: S-start state, HS-hormone secretion state, H1-intermediate state of S and HS, HC-hormone circulation state, H2-intermediate state between HS and HC and lastly HR-hormone receive state (final state).

HS, HC and HR state are shown along with O1, O2 and O3 respectively, which represent output alphabets. O1 represents hormone secretion event, O2 presents beginning of hormonal circulation through blood stream. O3 presents the hormone reception at target cells and the beginning of production of specific chemical for the need of body commanded by PIT (Fig. 1).

Table I shows the input values and assumptions of the Moore machine in Fig. 3. D(t), H(t), $H_p(t)$, $H_{rc}(t)$, $H_d(t)$, $B_c(t)$, $H_{fd}(t)$ are various signals in time domain which represent as in previous subsection (see section IV B). Few threshold values such as $D_{th}$, $H_{th}$, $H_{dth}$ are also described in the same sub section (see section IV B).

Table II presents input alphabets $\sum$ . Ten different alphabets are presented is the Table II, such as: $d_1$, $d_2$, $d_3$, $d_4$, $d_5$, $d_6$, $d_7$, $d_8$, $d_9$ and $d_{10}$. Each input alphabet originates from specific numerical inequality as follows: $d_1$: $D(t) >= D_{th}$, $d_2$: $D(t) < D_{th}$, $d_3$: $H(t) < H_{th}$, $d_4$: $H(t) >= H_{th}$, $d_5$: $H_p(t) >= B_c(t) + H_{fd}(t)$, $d_6$: $H_p(t) < B_c(t) + H_{fd}(t)$, $d_7$: $H_d(t) < H_{dth}$, $d_8$: $Hd(t) >= H_{dth}$, $d_9$: $H_{rc}(t) > 0$, $d_{10}$: $H_{rc}(t) <= 0$. When any alphabet is read by any state in the Moore machine the state transition occurs. TABLE III presents the output function $\tau$ of the Moore machine, where six states and their corresponding outputs are shown. States HS, HC, and HR are associated with outputs O1, O2, and O3 respectively. While other three states such as: S, H1, and H2 are associated to $\epsilon$

- *Moore machine states:* The Moore machine presented in Fig. 3 has six states: Q={S, H1, HS, H2, HC, HR}
- *Moore machine alphabets:* The Moore machine has twelve alphabets shown in Table II. $\sum = \{d_1, d_2, d_3, d_4, d_5, d_6, d_7, d_8, d_9, d_{10}\}$
- *Moore machine output alphabets:* The Moore machine has three output alphabets: $\Lambda = \{O_1, O_2, O_3\}$




DOI: 01.IJRTET.8.1.35

Int. J. on Recent Trends in Engineering and Technology, Vol. 8, No. 1, Jan 2013

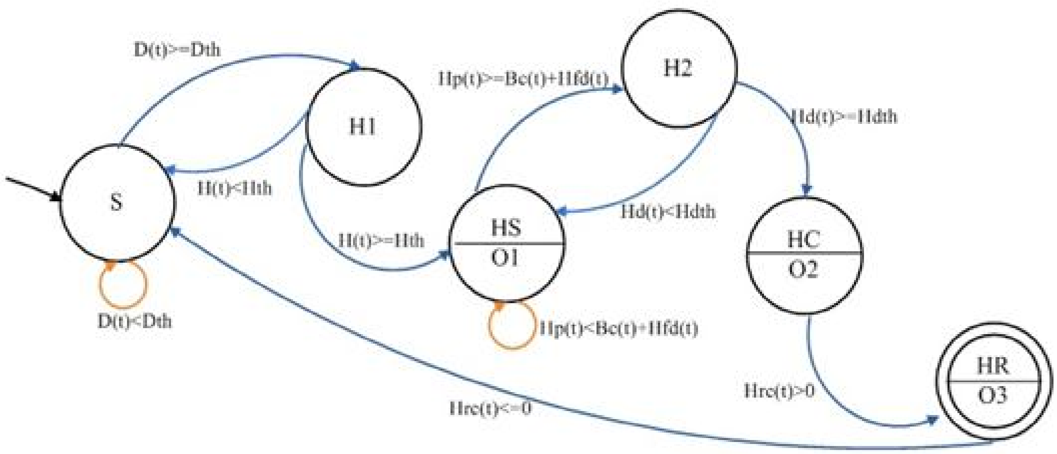


Figure 3. Moore machine representation of hormonal molecular communication channel

TABLE I. INPUT VALUES AND ASSUMPTIONS

| Input values | Assumptions |
|---|---|
| D(t) | disturbance factor |
| $D_{th}$ | Disturbance threshold value |
| H(t) | Nervous network control over hormone regulation |
| $H_{th}$ | Hormonal regulatory threshold controlled by nervous network |
| $H_p(t)$ | Hormonal propagation rate |
| $B_c(t)$ | Blood circulation rate |
| $H_{fd}(t)$ | Hormonal free diffusion rate |
| $H_d(t)$ | Hormonal successful delivery rate |
| $H_{dth}$ | Hormone delivery threshold rate |
| $H_{rc}(t)$ | Hormone reception rate |

TABLE II. ALPHABET-$\sum$

| Input values | Resultants |
|---|---|
| $d_1$ | $D(t) >= D_{th}$ |
| $d_2$ | $D(t) < D_{th}$ |
| $d_3$ | $H(t) < H_{th}$ |
| $d_4$ | $H(t) >= H_{th}$ |
| $d_5$ | $H_p(t) >= B_c(t) + H_{fd}(t)$ |
| $d_6$ | $H_p(t) < B_c(t) + H_{fd}(t)$ |
| $d_7$ | $H_d(t) < H_{dth}$ |
| $d_8$ | $H_d(t) >= H_{dth}$ |
| $d_9$ | $H_{rc}(t) > 0$ |
| $d_{10}$ | $H_{rc}(t) <= 0$ |

- *Moore machine output function:* The Moore machine output function is presented in Table III.
- *Moore machine start state:* The Moore machine start state is: $q_0$=S.
- *Final state:* The Moore machine final state is: F=HR

TABLE III. OUTPUT- $\tau$

| States | S | H1 | HS | H2 | HC | HR |
|---|---|---|---|---|---|---|
| Output | ε | ε | $O_1$ | ε | $O_2$ | $O_3$ |

$d_x$/ - presents the action/event concept where x-1,2,3,…,10. ε is the event that means impossible or illegal event shown in Table IV.

TABLE IV. STATE TRANSITION TABLE

| | S | H1 | HS | H2 | HC | HR |
|---|---|---|---|---|---|---|
| S | $d_2$/ ε | $d_1$/ ε | --- | --- | --- | --- |
| H1 | $d_3$/ ε | --- | $d_4$/ $O_1$ | --- | --- | --- |
| HS | --- | --- | $d_6$/ $O_1$ | $d_5$/ ε | --- | --- |
| H2 | --- | --- | $D_7$/ $O_1$ | --- | $d_8$/$O_2$ | --- |
| HC | --- | --- | --- | --- | --- | $d_9$/$O_3$ |
| HR | $d_{10}$/ ε | --- | --- | --- | --- | --- |

## V. NANO COMPUTER DESIGN

Fig 4. presents the novel nano computer based on hormonal molecular communication channel. It consists of four parts as below:

*Input:* neuronal spikes (H(t)) are fed into the computer for processing.

*Storage Unit*: this part of nano computer receives and stores temporarily the neuro signal and sends it to Processing Unit for further computation.

*Processing Unit:* the PU receives the sensing information from Storage Unit and performs some simple operations, such as the comparison of that information with some predetermined thresholds values by implementing the derived *Moore machine*. This resembles to the hormone transmission phase of HCA.


DOI: 01.IJRTET.8.1.35

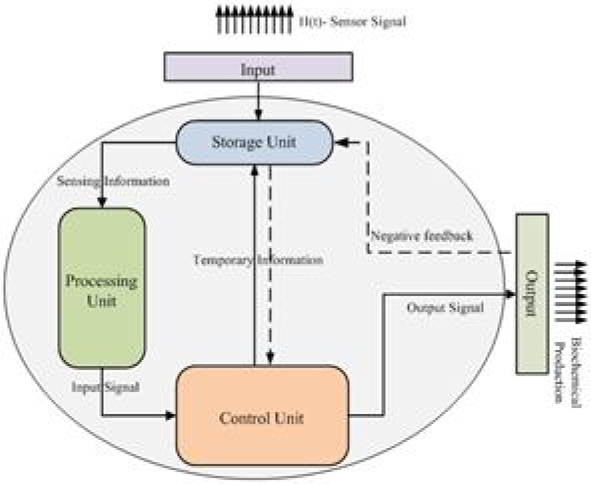


Figure 4. Nano computer architecture based on hormonal molecular communication channel.

*Control Unit:* the CU takes the inputs that come from the Processing Unit, performs few predefined computations and provides the environment same to the hormone circulation phase of HCA.

*Output:* after getting command from CU, actuator signal is generated which produces specific biochemical that is needed for human body. Based upon concentration and other vital information of outputted biochemical molecules, a negative feedback is sent to CU through storage unit.

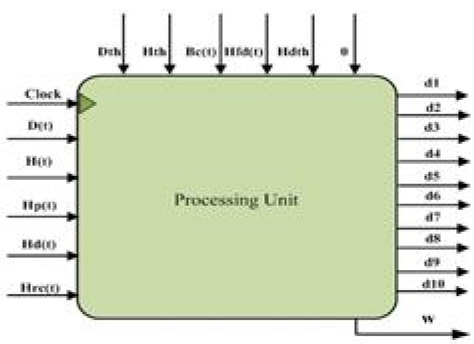


Figure 5. Processor unit.

*Processing Unit*: it does the vital computation of decision making by incorporating different inputs presented in Table I. and Table II (Fig. 5). Clock signal and wait signal (w) are used to synchronize the input values of the operations and to control the rate with which the nano computer generates actuator signal to manufacture biochemical need for human body.

## Conclusions

This paper presents novel algorithm on hormonal communication channel (HCA). A Moore machine based on the HCA is also devised. Later, a nano computer is developed that works on Moore machine logic. This paper is novel in its nature to fulfill the futuristic aspects of ICT based high tech medical diagnostic technique development. Simulation of the HCA should be done in future. Being a theoretical model the, nano computer should be analyzed to compute its efficiency.

## References

[1] Nanonetwork, http://en.wikipedia.org/wiki/Nanonetwork.

[2] P. P. Ray, "Nano Computer Design Based on Intra Body Nanoscale Neuro-Spike Communication: a Nanonetwork Paradigm", accepted in *CODIS* 2012.

[3] P. P. Ray, "Communication Channel Modeling and Automata Designing of Human Auditory System", accepted in *CEE* 2012.

[4] D. Malak, O. B. Akan, "Molecular communication nanonetworks inside human body", *Nano Communication Networks*, Vol. 3, pp. 19–35, 2012.

[5] A. Guney, B. Atakan, and O. B. Akan, "Mobile Ad Hoc Nanonetworks with Collision-based Molecular Communication", *IEEE Transactions on Mobile Computing*, Vol. 11(3), pp. 353- 366 , 2012.

[6] M. Pierobon, I.F. Akyildiz, "A physical channel model for molecular communication in nanonetworks", *IEEE Journal on Selected Areas in Communications (J-SAC)*, 28, pp. 602–611. (May) 2010.

[7] A. V. Goltsev, F. V. de Abreu, S. N. Dorogovtsev, and J. F. F. Mendes, "Stochastic cellular automata model of neural networks", *arXiv*:0904.2189v3, pp. 1-10, 2010.

[8] B. Atakan, O.B. Akan, "An information theoretical approach for molecular communication", in Proceedings of *ICST/ACM BIONETICS*, pp. 33–40, 2007.

[9] B. Atakan, O.B. Akan, "On channel capacity and error compensation in molecular communication", *Springer Transactions on Computational Systems Biology* 10, pp. 59–80. (February) 2008.

[10] J. Q. Liu, T. Nakano, An information theoretic model of molecular communication based on cellular signaling, in *Bio-Inspired Models of Network, Information and Computing Systems*, pp. 316-321, 2007.

[11] S. A. Cavalle, "Automata Modeling of Quorum Sensing for Nanocommunication Networks", Thesis, 2010.

[12] E. Balevi, O.B. Akan, "A physical channel model of nanoscale neurospike communication", 2011.

[13] E. Balevi, O.B. Akan, "Synaptic Gaussian multiple access channel", 2011.

[14] Hormone, http://en.wikipedia.org/wiki/Hormone.

[15] A.C. Guyton, J.E. Hall, Textbook of Medical Physiology, *W.B. Saunders*, Philadelphia, 2006.


DOI: 01.IJRTET.8.1.35

ACEEE